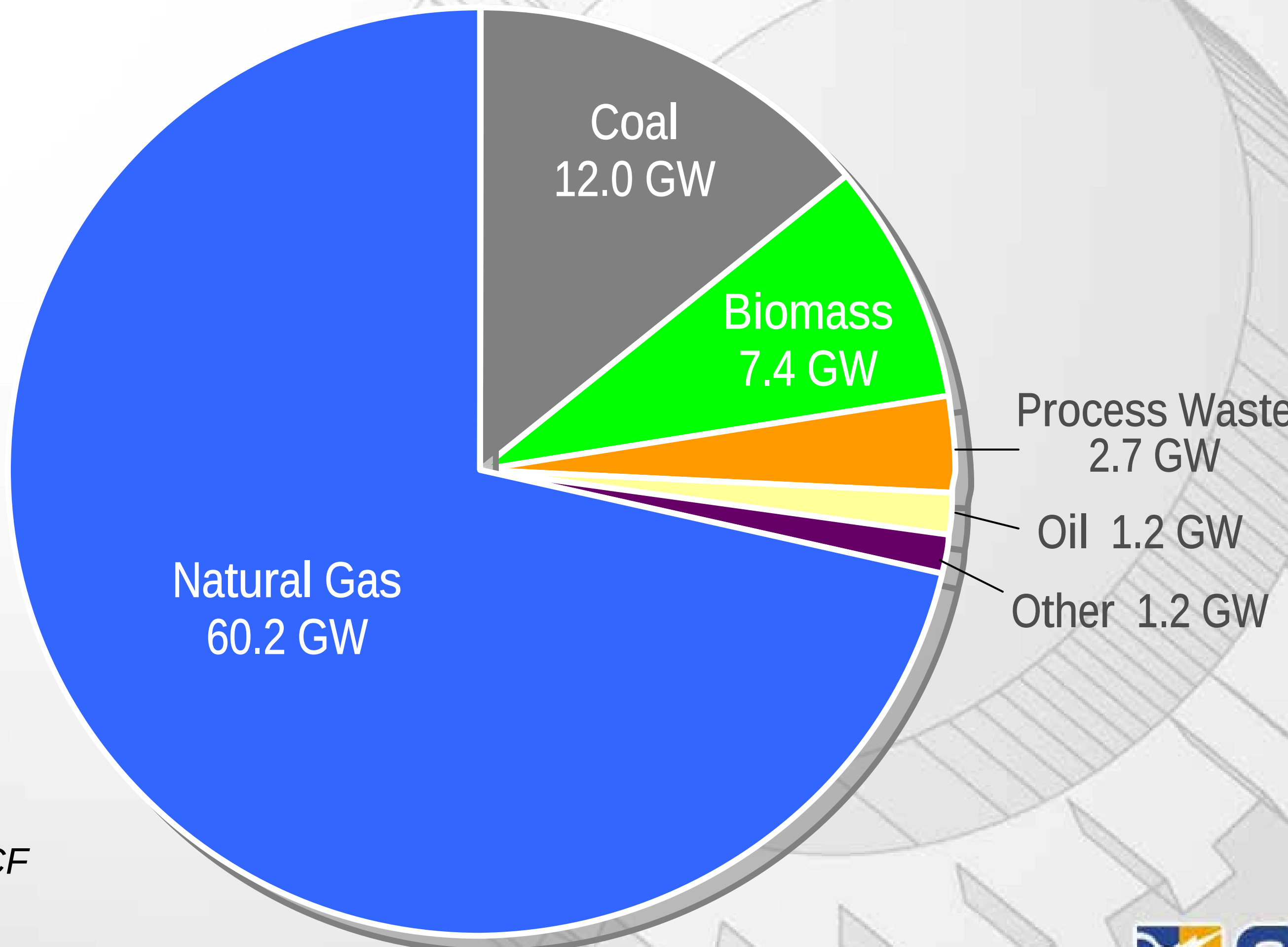
Biomass CHP: An Overview

Bruce Hedman
ICF International
BHedman@icfi.com
EPA Combined Heat and Power Partnership Webinar
June 25, 2009

Agenda

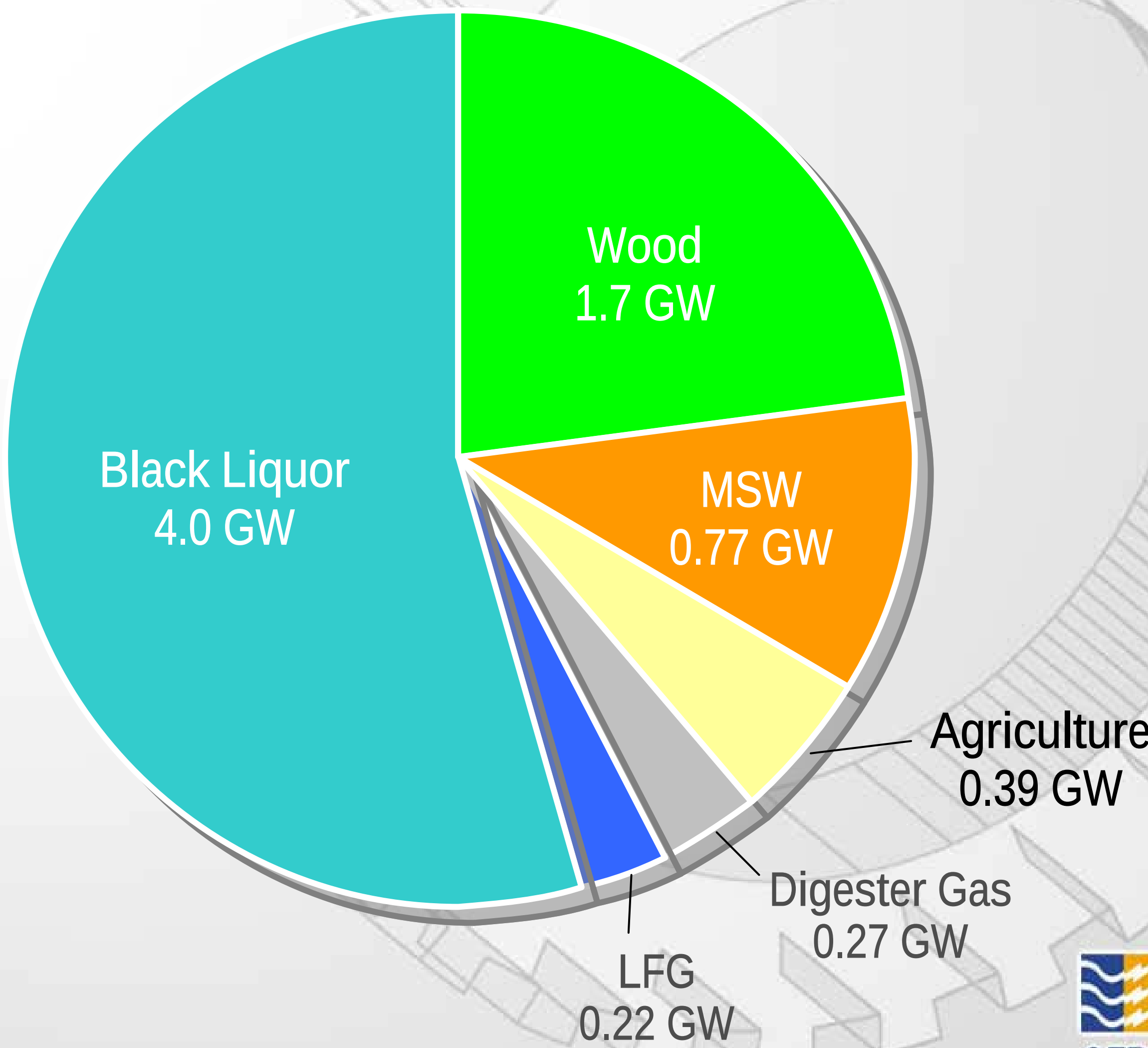
- Existing Biomass CHP
- Biomass Resource Base
  - Types
  - Costs
  - Issues
- Biomass Conversion Technologies
  - Direct Combustion
  - Gasification
  - Modular

Biomass Is Already an Important Fuel Source for CHP



Source: ICF

Wood or Wood Byproducts Represent the Majority of Existing Biomass CHP

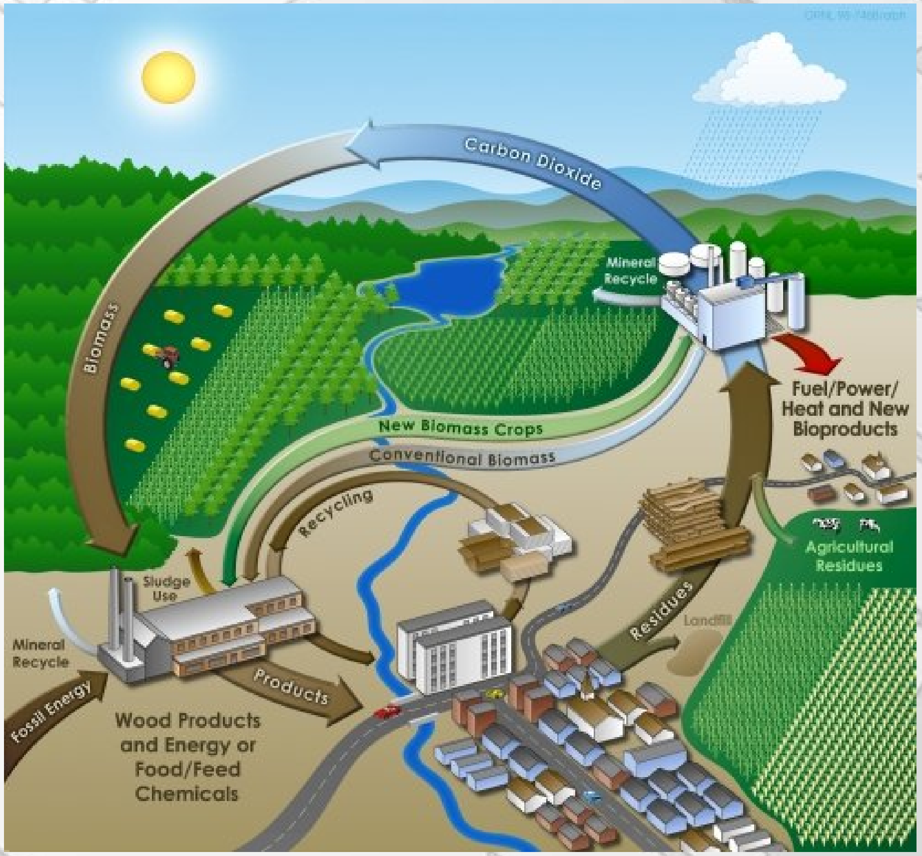


Source: ICF

COMBINED HEAT AND POWER PARTNERSHIP

Why Use Biomass?

- Can be less expensive than fossil fuels
- Avoids disposal charges
- Government incentives
- Biomass is CO_2 neutral

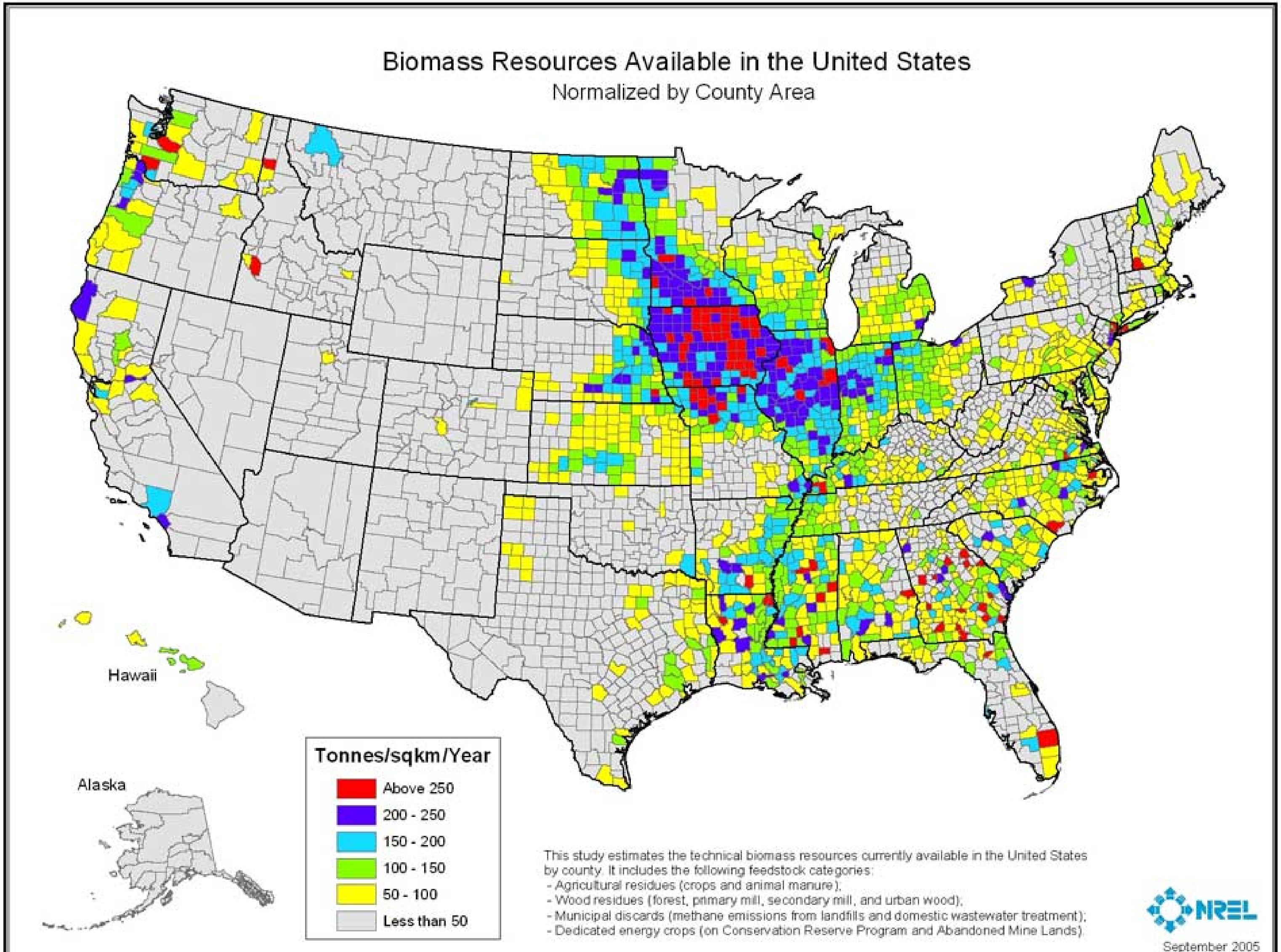


CHP
EPA COMBINED HEAT AND POWER PARTNERSHIP

Biomass Resources

- Rural Resources
  - Forest residues and wood waste
  - Crop residues
  - Energy crops
  - Agricultural biogas
- Urban Resources
  - Urban wood waste
  - Landfill gas
  - Wastewater treatment gas
  - Food processing residues

Where is the Biomass Resource Base?



Biomass Fuel Considerations

- Energy and moisture content
- Seasonality of the resource
- Proximity to the generation site
- Alternative uses (affects availability and price)
- Reliability of fuel quality
- Weather related issues

Biomass Fuel Characteristics

Resource	Energy Content, Wet (Btu/lb)	Energy Content, Dry (Btu/lb)	Cost ($/ton)	Cost ($/MMBtu)
Forest residue	5,140	8,570	15 - 30	1.50 – 2.95
Forest thinnings	5,140	8,570	15 - 30	1.50 – 2.95
Mill residue		8,570	8 - 50	0.50 – 2.95
Corn stover	5,290	7,560	20 - 40	1.90 – 3.80
Wheat straw	5,470	6,840	40 - 50	4.00 – 5.00
Hybrid poplar/willow	4,100	8,200	30 – 60	4.75 – 7.50
Switchgrass	6,060	8,670	35 - 50	2.90 – 4.25
Urban wood waste	4,600	6,150	3 - 24	0.50 – 2.80
Food processing residue	Case by case			1.25 – 2.50
Landfill gas	350 – 650 Btu/scf			1.00 – 3.00*
Manure biogas	600 – 800 Btu/scf			Variable*
WWT biogas	500 – 650 Btu/scf			Variable*

* May require treatment and clean-up costs

Source: Biomass CHP Catalog of Technologies, EPA CHP Partnership

CHP
EPA COMBINED HEAT AND POWER PARTNERSHIP

What Makes up the Cost of Biomass Fuel?

- Collection method
  - One of the largest costs for forest residue
  - Can be 20 to 25% of delivered cost for agricultural residue
- Resource cost
  - Usually some cost for agricultural residue and energy crops
- Transportation
  - Site specific and highly dependent on distance – usually too expensive if greater than 50 - 100 miles
- Storage
  - There is a cost involved whether stored where collected or at the point of use

Biomass Preparation Adds to Cost

- Receiving
  - Truck tipper, conveyer, radial stacker
- Processing
  - Metal separator, dryer, screener and grinder
- Buffer storage
  - 2 to 3 day capacity
- Fuel metering
  - Conveyers, meters, pneumatic transport

EPA CHP COMBINED HEAT AND POWER PARTNERSHIP

An Example of Biomass Fuel Emissions

Resource	SOx, lb/MWh	NOx, lb/MWh	CO, b/MWh	PM-10, lb/MWh	Comments
Biomass Technology (Wood biomass - unspecified)					
Stoker Boiler, Wood Residues	0.080	2.1	12.2	0.50 (total part.)	Based on 23 California grate boilers - uncontrolled
Fluidized Bed, Biomass	0.08	0.9	0.17	0.3	Based on 11 California fluid bed boilers
Coal Technology					
Bituminous Coal Stoker Boiler	20.2 (1% S coal)	5.8	2.7	0.62	PM Control only (baghouse)
Pulverized Coal Boiler	14.3	6.9	0.35	0.32 (total part.)	Average US PC boiler (baghouse and FGC)
Fluidized Bed Coal Boiler	3.7	2.7	0.35	0.30 (total part.)	Baghouse for PM, Ca sorbents for SOx

Source: Richard Bain, NREL, Introduction to Biomass Thermal Conversion, August 2, 2004

Things to Consider when Evaluating Biomass as a Fuel

- It costs money to transport biomass fuel
- It costs money to store and process biomass fuel
- Particulate and CO emissions may be an issue
- Biomass produces ash that must be disposed
- Biomass fuel procurement can be a full time job

Biomass Conversion Options

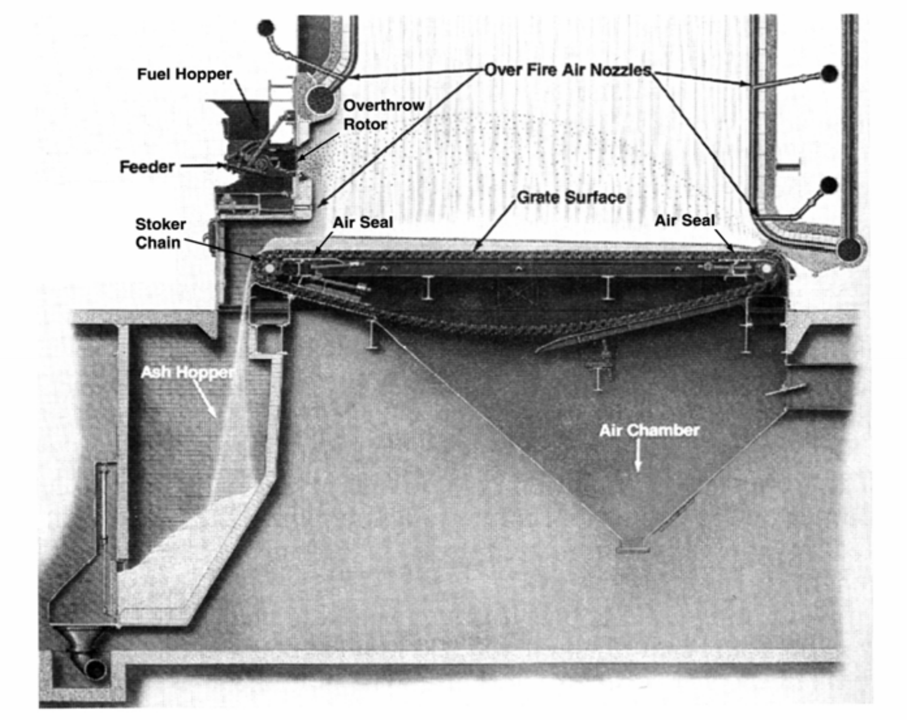
- Direct fired combustion
  - Biomass fired in a conventional boiler to produce steam for steam turbine generator and process heating
- Gasification
  - Heating biomass in an oxygen reduced atmosphere to produce a syngas that could be used in boilers or directly in engines and turbines
- Modular biopower
  - Small scale integrated systems to produce power and heat
- Cofiring
  - Substituting biomass for a portion of the coal in large coal-fired systems

Direct Combustion vs Gasification

	Direct Combustion	Gasification
Purpose	Generation of heat	Creation of higher value fuel from waste or lower value material
Process	Complete combustion with excess oxygen	Thermochemical conversion with limited or no oxygen
Raw Gas	CO_2, H_2O, SO_2, NO_x, particulates	H_2, CO, H_2S, NH_3O, particulates
Gas Clean-up	Treated flue gas discharged to atmosphere; Clean flue gas primarily CO_2 and H_2O	Syngas clean-up at atmospheric to high pressure; Clean syngas primarily CO and H_2
Solid Byproducts	Bottom ash and fly ash collected, treated and disposed; can be classified as hazardous	Low temperature processes produce char that can be used as fuel; High temperature processes produce a non-leaching, non-hazardous slag
Temperature	1500 – 1800 F	1300 – 2700 F
Pressure	Atmospheric	Atmospheric to high pressure
CHP Operation	Steam turbine Rankine cycle, low power to heat ratio	Steam turbine Rankine cycle, or direct use by engines and gas turbines with heat recovery, higher power to heat ratios
Commercial Status	Commercially available, biomass boilers have long operating history	Steam turbine systems commercially available; engine/turbine systems being demonstrated

Direct-Fired Biomass Boilers - Stoker

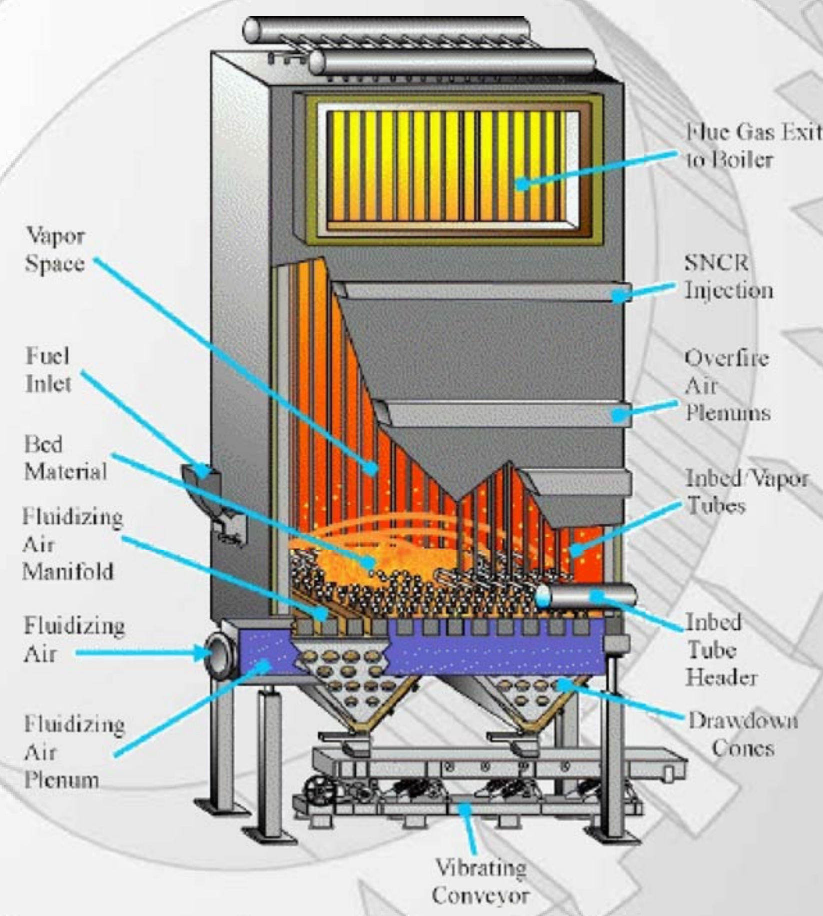
- Traditional solid fuel technology
- Fuel burns on a grate with high levels of excess air
- Four elements
  - Mechanical fuel admission
  - Stationary or moving grate
  - Overfire air system for complete combustion
  - Ash discharge system



Source: ORNL, 2002.

Direct-Fired Biomass Boilers – Fluidized Bed

- Newer technology developed to reduce emissions from coal firing
- Fuel is burned in a bed of hot inert particles suspended by an upward flow of combustion air
- Fluidized bed process efficiently mixes fuel and air – increasing both the rate and efficiency of the combustion process
- Allows a more compact design
- Well suited to burn biomass and other low-grade fuels
- Lower combustion temperatures reduces NOx emissions



EPA CHP COMBINED HEAT AND POWER PARTNERSHIP

Direct Combustion Biomass CHP

- Limited to steam turbine CHP
  – low power to heat systems
- Commercially available equipment with long operating histories
- Reliability of boilers, steam turbines and auxiliary systems extremely high
- All-in costs (fuel prep yard, boiler, steam turbine generator, emissions control, interconnection): $2,500 to $6,000/kW (function of size and location)

Biomass Gasification (Thermochemical)

- Heating solid biomass in an oxygen reduced environment to make low or medium Btu syngas (100 to 500 Btu/scf)
  - Heating value primarily from CO and H_2
  - Remaining constituents consist of CO_2 and other non-combustible gases
- Syngas is more versatile than solid fuel – can be used in boilers, process heaters, mixed with other gaseous fuels, and, if properly cleaned, in turbines, engines and fuel cells
- Gasification can remove fuel contaminants and reduce emissions compared to direct fired biomass systems
- Gasification can be designed to handle a wide range of biomass feedstocks and waste fuels

Types of Gasifiers

	Advantages	Disadvantages
Fixed Bed - Updraft	•Simple, low cost process •Able to handle high moisture and high inorganic content	•Contains 10 to 20% tar by weight, requiring gas clean-up for use in engines or turbines
Fixed Bed - Downdraft	•Simple, low cost process •Up to 99% of the tar is consumed •Minerals remain with char/ash, reducing the need for cyclone	•Requires low moisture content (<20%) •Syngas exiting the reactor is at high temperature •4 to 7% of carbon remains unconverted
Fluidized Bed – Bubbling and circulating	•Able to accept a wide range of fuel particle sizes, including fines •High conversion rates with reduced tar and low unconverted carbon •High heat transfer rates	•More complicated system •High particulate loading •Equipment erosion from high gas and particle velocity
Plasma	•High temperature process that destroys hazardous materials (MSW) •No bottom ash or fly	•Electrical process •Relatively new process – limited experience base

Biomass Gasification CHP

- Biomass gasification currently commercially available for heating and steam turbine CHP
  - Most experience is with coal and coke
  - More biomass gasification experience in Europe than the U.S.
- Demonstrations planned with recip engines and gas turbines
  - Gas clean-up and conditioning is key
- Gasifier conversion efficiencies can range from 65 to 80%
- Costs are expected to come down as technology matures and infrastructure develops

CHP
EPA COMBINED HEAT AND POWER PARTNERSHIP

Modular Biomass CHP

- Small scale biomass systems in pre-engineered and packaged modules (< 1 MW)
- Based on both direct fired and gasification technologies
- Usually include conversion equipment, generator and heat recovery/steam generator
- Fuel storage and delivery system must be added
- Applicable to rural/remote areas and small/medium commercial and institutional applications

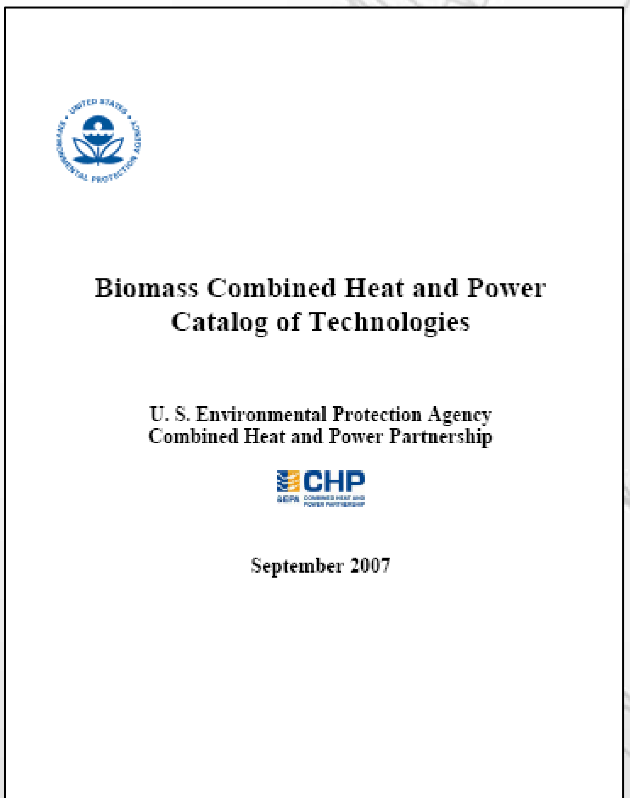
Source: Chiptec

Critical Success factors for Biomass CHP

- Location is key – Biomass is a local fuel with relatively low energy density. Transportation costs become very significant after 20 miles
- Design for fuel flexibility – Old fuel sources can dry up and new sources become available
- Prep yard and fuel feed systems need to be properly planned, designed and operated – Many installations spend time and money to solve problems in the feed system.
- Place a high value on reliability and dependability in plant design, equipment selection and during operation

For More Information

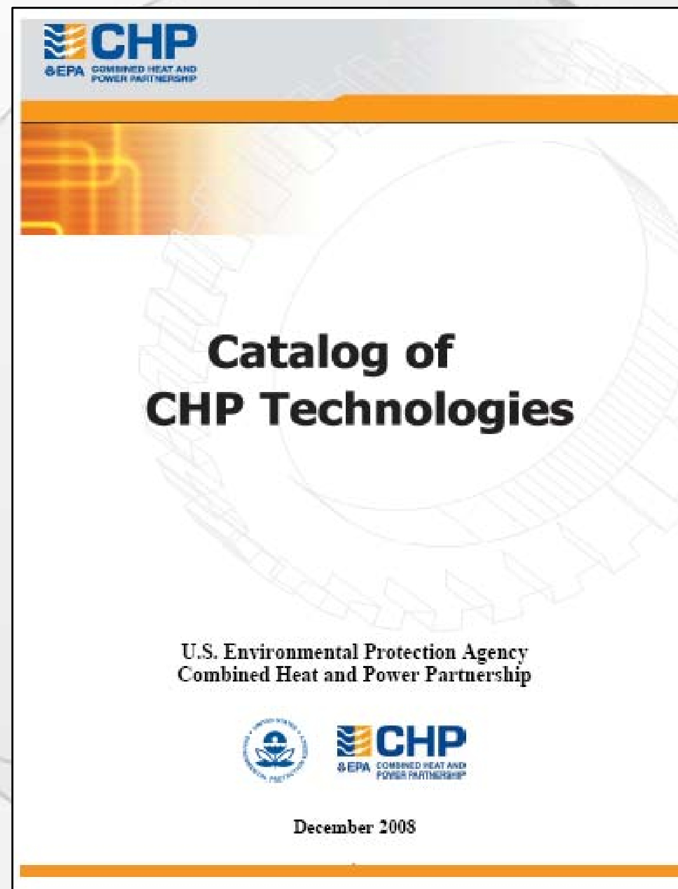
www.epa.gov/chp



Biomass Combined Heat and Power
Catalog of Technologies

U. S. Environmental Protection Agency
Combined Heat and Power Partnership

September 2007



Catalog of
CHP Technologies

U.S. Environmental Protection Agency
Combined Heat and Power Partnership

December 2008

Biomass CHP

APPENDIX

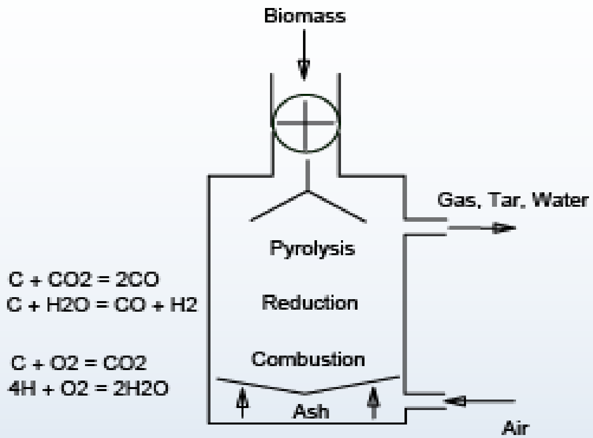
Biomass Boiler Characteristics

Boiler Type	Common Fuel Types	Feed Size	Moisture Content	Boiler Efficiency	Capacity Ranges
Stoker	Sawdust, bark, chips, hog duel, shavings, end cuts, sander dust	0.25 – 2 in.	10 – 50%	70 to 78%	Up to 100 MW (many in the 5 to 20 MW range)
Fluidized bed	Wood residue, peat, wide variety of fuels	< 2 in.	< 60%	75 to 82%	Up to 300+ MW (many in the 20 to 50 MW range)

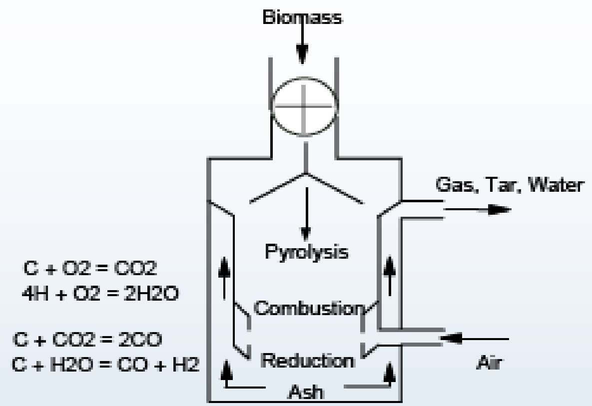
Stoker and Fluidized Bed Boiler Comparison

Feature	Boiler Type	
	Stoker	**Fluidized Bed**
Combustion Mechanism		
Combustion zone	On the stoker	Entire area of furnace
Mass transfer	Slow	Active vertical movement – both mass and heat transfer
Combustion Control		
Responsiveness	Slow response	Quick response
Excess air control	Fair	Good
Fuel Issues		
Applicability to various fuels	Fair	Good
Fuel pretreatment	Generally not needed	Lumps must be crushed
Environmental Factors		
Low SOx combustion	No in-furnace desulfurization	High rate of in-furnace desulfurization
Low NOx combustion	Difficult	Inherently low
Economics		
Appropriate facility size	Small	Medium to large
Installed costs ($/lb of steam)	$90 (250,000 lb/hr) – $150 (20,000 lb/hr)	$125 (250,000 lb/hr) – $350 (20,000 lb/hr)

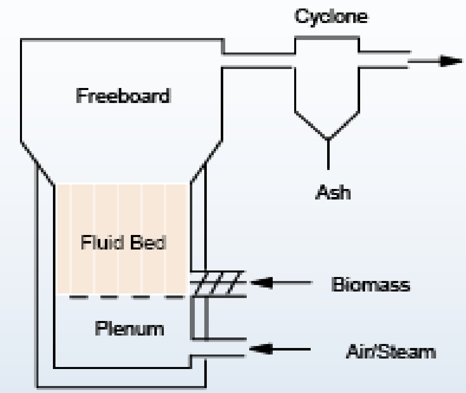
Biomass Gasifier Types



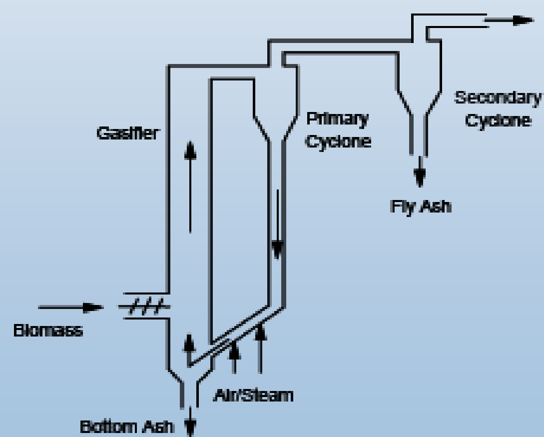
Updraft Gasifier



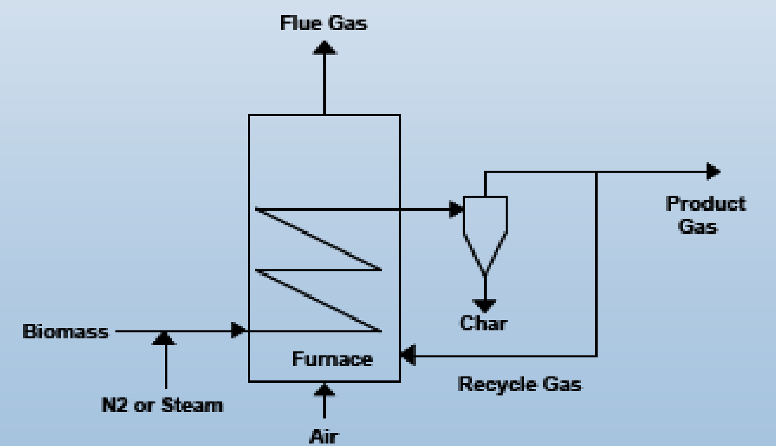
Downdraft Gasifier



Fluid-Bed Gasifier



Circulating Fluid-Bed Gasifier



Entrained Flow Gasifier

Gasifier Characteristics

Gasifier	Advantages	Disadvantages
Updraft fixed bed	Mature for heat Small-scale applications (<5MW) Can handle high moisture No carbon in ash	Feed size limits High tar yields Scale limitations Low Btu gas Slagging potential
Downdraft fixed bed	Small-scale applications (<5MW) Low particulates Low tar	Feed size limits Scale limitations Low Btu gas Moisture-sensitive
Bubbling fluid bed	Large-scale applications Feed characteristics Direct/indirect heating Can produce higher Btu gas	Medium tar yield Higher particle loading
Circulating fluid bed	Large-scale applications Feed characteristics Can produce higher Btu gas	Medium tar yield Higher particle loading
Entrained flow fluid bed	Can be scaled Potential for low tar Potential for low methane Can produce higher Btu gas	Large amount of carrier gas Higher particle loading Particle size limits

Source: Richard Bain, NREL, Introduction to Biomass Thermal Conversion, August 2, 2004

Syngas Clean-up Issues

Contaminant	Description	Treatment
Tar	Tars (creosote) are complex hydrocarbons that persist as condensable vapors.	Wet scrubbers, electrostatic precipitators, barrier filters, catalysts, or combustion.
Particles	Particles are very small, solid materials that typically include ash and unconverted biomass.	Cyclone separators, fabric filters, electrostatic precipitators, and wet scrubbers.
Alkali compounds	Potassium, alkali salts, and condensed alkali vapors are part of the chemical composition of biomass.	First, cool syngas below 1,200º F, causing the alkali vapors to condense. Second, use cyclone separators, fine fabric filters, electrostatic precipitators, and wet scrubbers.
Ammonia	Ammonia is formed from nitrogen (fuel-bound and in air) and hydrogen (in fuel and in moisture content). When syngas is burned, ammonia is converted to NO_x.	Catalysts, hydrocarbon reforming, or wet scrubbing.